

12-7

02.15002 VO2

**ON-FARM
IRRIGATION EFFICIENCY**

SPECIAL TECHNICAL REPORT

COACHELLA VALLEY WATER DISTRICT

APRIL 1993



Boyle Engineering Corporation

consulting engineers / architects



**Boyle
Engineering
Corporation**

consulting engineers / architects

Suite 176
1300 East Shaw Avenue
Fresno, California 93710

Telephone: 209 / 222-8436
Telecopier: 209 / 222-8430

ON-FARM

IRRIGATION EFFICIENCY

SPECIAL TECHNICAL REPORT

COACHELLA VALLEY WATER DISTRICT



**Stuart Styles, PE
Project Manager**

APRIL 1993

TABLE OF CONTENTS

<i>Section 1</i>	EXECUTIVE SUMMARY	
<i>Section 2</i>	INTRODUCTION	
	2.1 Project Objective	2-1
	2.2 Area of Study.....	2-1
	2.3 Importance of Study	2-5
	2.4 Standard Definitions	2-6
	2.5 Why 1987 Was Selected.....	2-9
<i>Section 3</i>	ON-FARM IRRIGATION EFFICIENCY	
<i>Section 4</i>	ON-FARM IRRIGATION EFFLUENT AND DISTRIBUTION UNIFORMITY	
	4.1 Distribution Uniformity	4-1
	4.2 Results from Other Regions	4-3
	4.3 Irrigation Efficiency	4-3
<i>Section 5</i>	WATER AVAILABILITY IN STUDY AREA	
	5.1 Surface Water Delivery	5-1
	5.2 Irrigated Acreage.....	5-1
	5.3 Groundwater Pumping	5-2
	5.3.1 Groundwater Usage in CVWD	5-2
	5.3.2 Notes from Coachella Valley Groundwater Reports	5-2
	5.3.3 CVWD Agricultural Groundwater Pumping Calculations	5-8
	5.4 Total On-Farm Water Availability in 1987	5-16
<i>Section 6</i>	BENEFICIAL USES OF WATER	
	6.1 Method of Estimating Crop Water Use	6-1
	6.1.1 Crop Coefficients and ETo.....	6-1
	6.1.2 Published Crop ET Data	6-2
	6.1.3 Summary of Crop ET Values	6-10

6.2	Estimated Crop Water Requirement.....	6-10
6.3	Estimated Long-Term Leaching Requirement	6-10
6.4	Estimated Effective Rain.....	6-15
6.5	Irrigation Efficiency	6-15

Section 7 **FINDINGS AND CONCLUSIONS**

Appendices

LIST OF FIGURES

2-1	Coachella Valley Water District Map	2-2
2-2	East and West Colorado River Basins	2-3
4-1	Distribution Uniformity, Water Destination Diagram.....	4-2
5-1	Groundwater Basin Profile	5-5
5-2	Groundwater Elevations Near Valerie	5-7
5-3	Total PA Energy Use in Coachella Valley.....	5-9
6-1	Summary Alfalfa Crop ETc Calculation.....	6-12

LIST OF TABLES

5-1	CVWD - 1987 Crop Acreage Summary.....	5-3
5-2	Summary of Water Applied Outside CVWD Command Area.....	5-12
5-3	Summary of Water Applied to Microirrigation Fields in Coachella Valley - 1987.....	5-15
6-1	CIMIS ETo Data.....	6-3
6-2	Published Growing Season ET Values.....	6-4
6-3	Various Referenced Citrus Crop ET Values.....	6-8
6-4	Summary CVWD Crop Kc Values	6-11
6-5	Summary of ETc and Acreage For CVWD	6-13
6-6	Salt Tolerance of Selected Crops	6-14
6-7	Summary of Total Rainfall in 1987	6-16

Section 1

EXECUTIVE SUMMARY

The average on-farm irrigation efficiency of the Coachella Valley Water District (CVWD) was evaluated for the year 1987. Reported values of high on-farm irrigation efficiency in recent litigation were questioned due to the sandy soils of the Coachella Valley and lack of metering of numerous irrigation wells used for pumping groundwater.

Detailed records were requested from CVWD to clarify differences found in the reported irrigated acreage and groundwater pumping volumes. CVWD did not supply those records even after four months. Furthermore, a draft report was provided to CVWD with agreed-upon time lines for review. CVWD was requested to provide input regarding any possible errors or incorrect assumptions in the report. CVWD opted not to comment on the draft report. At this time, the calculations are estimates based on the best information that was available from other sources.

The focus of this report was the on-farm irrigation efficiency of the CVWD. The area of the study is referred to as the "command area," which is that region of the Coachella Valley that receives a surface water supply from the Colorado River.

Published evaluations of the performance of irrigation systems in the CVWD were analyzed. The data indicated that on the potentially best performing irrigation system (drip), the distribution uniformity (not to be confused with "irrigation efficiency") was 76 percent. Since the majority of irrigation systems in the Coachella Valley are flood (surface) irrigation systems on sandy soils, the distribution uniformity must be much less than 76 percent for the entire district.

Irrigated acreage values reported by CVWD were checked against detailed data obtained from the California Department of Water Resources in a 1987 land use survey. It was found that significant acreage in the Coachella Valley is outside the area serviced by CVWD surface water connections. These areas are supplied entirely by groundwater. In addition, many of the growers inside the command area utilize wells to improve the flexibility of water delivery. Previous studies have not investigated and reported agricultural groundwater pumping volumes. This study utilized electrical power records to estimate the volume of groundwater pumping. In the study year, groundwater pumping inside the command area was estimated at about 87,000 acre-feet for 1987. This compares to a reported value by CVWD of only 34,400 acre-feet for the same year and same area.

Utilizing the power records to assess the amount of groundwater pumped, acreage data from DWR, and standard definitions for irrigation efficiency, the CVWD command area on-farm irrigation efficiency was 57 percent in 1987.

A simple check of CVWD drainage water salinity (2.4 dS/m) compared against the quality of Colorado River water (1.1 dS/m) shows a salinity concentrating effect of about 2:1 for the district. This indicates that the on-farm irrigation efficiency estimate of about 57 percent is reasonable.

Section 2

INTRODUCTION

This report provides the technical information required to calculate a value for the on-farm irrigation efficiency of the Coachella Valley Water District (CVWD) as shown on Figure 2-1. Recent information provided by CVWD has indicated that irrigation efficiency of the district was significantly higher than data provided by the U.S. Bureau of Reclamation (USBR). In 1979, the USBR reported on-farm irrigation efficiency ranging from 51 to 55 percent for CVWD from 1975 to 1978. Data provided by CVWD for the recent litigation involving flooding near the Salton Sea indicated deficit irrigations ranging from 27,000 to 115,000 acre-feet for CVWD from 1975 to 1990. Observations of the agronomic conditions of CVWD have not verified the impacts of deficit irrigations. This report investigated the on-farm irrigation efficiency using independent irrigated acreage values in the Coachella Valley.

Irrigation efficiency is defined as:

$$\text{Irrigation Efficiency (IE)} = \frac{\text{Irrigation Water Beneficially Used} \times 100}{\text{Irrigation Water Applied}} \quad \text{Eq. (2-1)}$$

The same definition of "irrigation efficiency" can be used for both on-farm efficiency and district-level efficiency. However, the values of those efficiencies will be different. For example, on-farm irrigation efficiencies do not include such factors as operational canal spill, evaporation/seepage from district canals and reservoirs, reuse of water within the district boundaries, or beneficial uses of on-farm spill water for maintaining environmentally acceptable water quality in district drains.

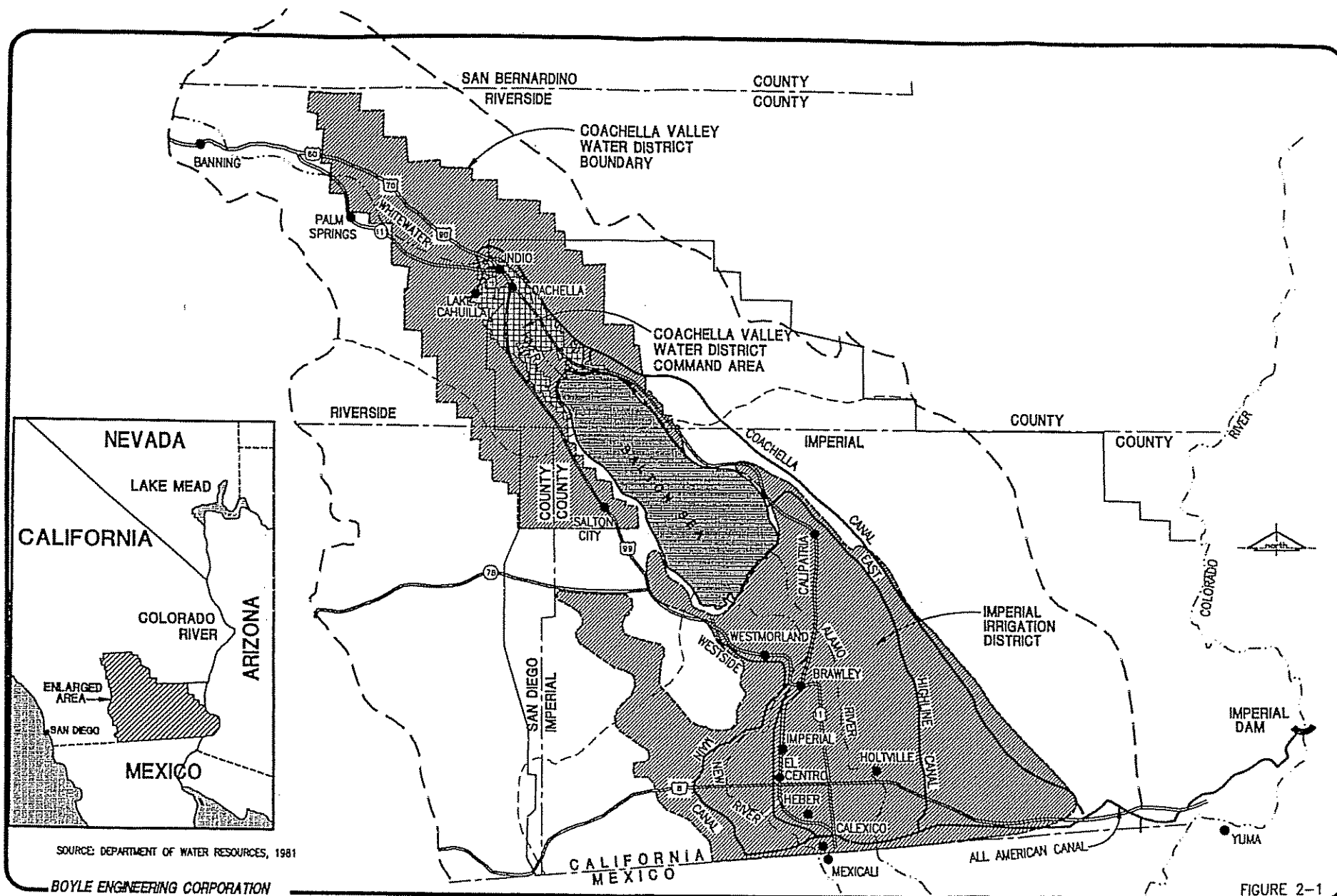
This report estimates the average on-farm irrigation efficiency, but does not provide a district-level irrigation efficiency. For CVWD, the district-level irrigation efficiency will be lower than the on-farm irrigation efficiency because of the existence of operational losses.

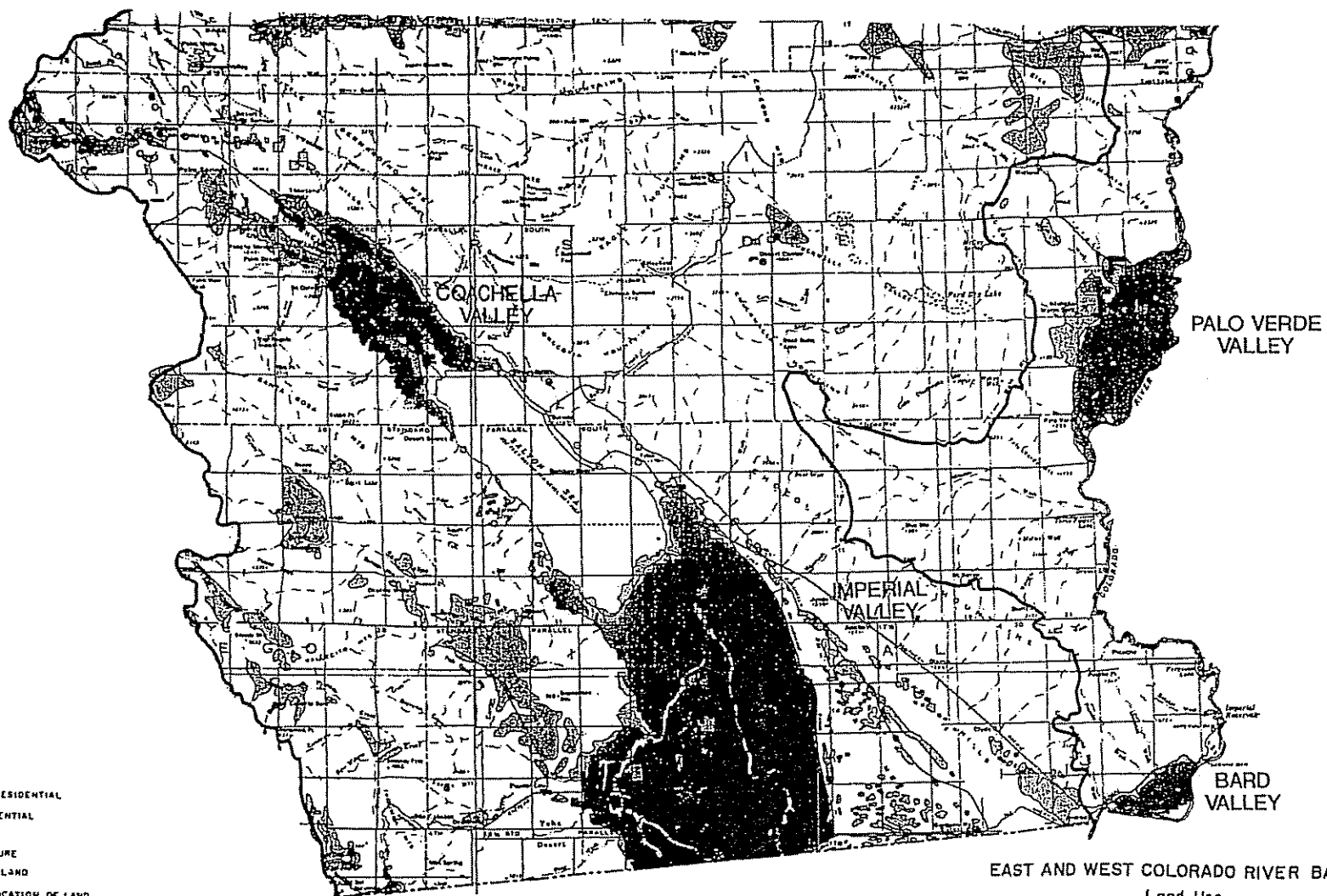
2.1 PROJECT OBJECTIVE

The project objective is to perform an independent analysis of the on-farm irrigation efficiency of waters delivered by CVWD for the calendar year 1987. The area to be studied is the command area, that portion of the Coachella Valley receiving surface water deliveries originating from the Colorado River for agricultural uses.

2.2 AREA OF STUDY

The Colorado River Basin consists of four productive agricultural valleys in the southeast desert area of California. Imperial, Bard, Palo Verde, and Coachella Valleys are shown on Figure 2-2.





LEGEND

- URBAN
- SCATTERED URBAN RESIDENTIAL
- RECREATIONAL RESIDENTIAL
- URBAN INDUSTRIAL
- IRRIGATED AGRICULTURE
- REMAINING IRRIGABLE LAND

CIRCLE SHOWS TYPE AND LOCATION OF LAND USE WHERE TOO SMALL TO BE MAPPED

REFERENCE: DWR DESERT AREAS AGRICULTURAL
LAND USE STUDY, 1972

EAST AND WEST COLORADO RIVER BASINS
Land Use
1972

The Imperial Valley is the largest area, having about 75 percent of the total irrigated area which is served by California's Colorado River agricultural supply. Coachella Valley represents about 10 percent of the total irrigated area of the four valleys. These areas started irrigating the desert around the turn of the twentieth century. In 1987, both districts received a proportion of the 3.85 million acre-feet of California's Colorado River entitlement.

Most of the lands in both districts slope toward a previously dry lake bed now referred to as the Salton Sea. The Salton Sea was created in 1905 when the Colorado River flowed unimpeded into the Imperial Valley for over two years. Today it represents one of the 10 largest lakes in the United States (excluding the great lakes). Since the initial flooding of river water, the Salton Sea has been maintained by agricultural runoff from Imperial, Coachella, and Mexicali Valleys with additional inflow from rainfall, storm runoff and groundwater flows. Evaporation is the only method by which water is removed from the sea.

Imperial Valley contains relatively recent deposits of water-transported soil (SCS 1981). The area is composed of recent alluvial and lacustrine deposits of the Colorado River. Material was moved from several states and irregularly distributed due to the river variations and fluctuations of the old lake that once existed in part of the area. Imperial Valley soils are typically a cracking clay as opposed to the coarser soils found in the Coachella Valley. Cracking clays are characterized as soils with high initial intake rates which nearly seal once the cracks have been filled. Soils of the Coachella Valley are composed of recent alluvium deposits of the Whitewater River and other local streams. Coarser soils are capable of higher infiltration rates throughout an irrigation event.

The growing season is year-round with temperatures exceeding 100°F occurring more than 100 days in the year. The annual frost-free growing season is about 300 days. These regions supply the United States with a large component of fresh vegetables and fruits consumed in the winter months. Historical precipitation is less than 3 inches per year.

Water supplies from an artesian basin underlying the Coachella Valley were the source of irrigation water for the Coachella Valley from 1902 until 1949. CVWD was organized in 1918 and covers over 650,000 acres. CVWD supplies Colorado River water to about one-tenth of the total area, referred to as the "command area" in this report. Irrigation water in CVWD's command area is supplied both by surface water deliveries and groundwater supplies pumped by individual landowners. There is also land outside of CVWD's command area that is supplied entirely by groundwater. The irrigated acreage reported by CVWD includes all irrigated land both inside and outside the command area. All of the urban water demands are supplied by the groundwater including golf courses and the resort areas near Palm Springs.

The district was organized in response to groundwater supplies which were rapidly being depleted. In 1949, the 124-mile Coachella branch of the All American Canal was constructed allowing CVWD growers to reduce the groundwater depletion and increase the amount of irrigated acreage. CVWD began receiving Colorado River water in 1949.

CVWD has almost 2,000 delivery points and maintains a delivery system primarily of buried pipelines to deliver water to each 40-acre parcel within the command area. During summer months, CVWD uses a rotation schedule for irrigation delivery due to limited supply capacity. This has resulted in many of the growers in the CVWD constructing on-farm reservoirs to allow

the growers additional flexibility in the irrigation of crops. Additionally, the majority of the acreage has access to groundwater from private wells.

CVWD experienced drainage problems prior to receiving surface waters from the All American Canal. After the surface water was introduced, a large portion of the area was affected by high water tables from a salty, perched water table. This shallow water table was (and is) being supplied by upslope irrigations that deep percolated to this unusable aquifer. CVWD installed open drains, buried pipe drains, and concrete-lined drains connecting a tile outlet to each 40-acre parcel. There is not a provision to remove surface runoff (tailwater)--only the subsurface flows. Over half of the irrigated acreage in the CVWD command area has the capability to remove subsurface flows. A large, unknown component of subsurface flows from the semiperched zone goes directly to the Salton Sea and is not monitored. The CVWD command area overlies a shallow aquitard that separates an upper and lower aquifer. Growers in the lower Coachella Valley pump groundwater from the lower aquifer zone. The upper, semiperched zone is supplied by overirrigation with some of this penetrating into the lower aquifer. Some of the subsurface flow is intercepted by the tile systems. The remainder of the perched water flow goes underground directly into the Salton Sea.

2.3 IMPORTANCE OF STUDY

Litigation starting in the mid-1970s was in response to rising waters in the Salton Sea creating flooding conditions on properties surrounding the Salton Sea. Property owners brought cases against CVWD and Imperial Irrigation District (IID) for compensation of flooded lands. After years of a common struggle to bring irrigation to the desert, the districts were on opposite sides of the courtroom debating the amount of liability in several lawsuits. The DWR published a report in 1981 stating the potential for 438,000 acre-feet of water savings in the Imperial Valley. In 1984, the USBR made a similar finding for the Imperial Valley and stated 350,000 acre-feet of water could be conserved. The State Water Resources Control Board (SWRCB) issued Decision 88-20 requiring IID to conserve 100,000 acre-feet by 1994. IID entered into an agreement with Metropolitan Water District (MWD) of Southern California to pay \$98 million for capital improvement projects and annually transfer about 106,000 acre-feet of conserved water to MWD for 35 years. This landmark agreement will be fully implemented in 1995.

Various reports have been generated over the years by consultants, government agencies, and the district regarding irrigation efficiencies. Discussions regarding efficiency often do not clarify the efficiency definition or the boundaries of the area described (i.e., whether the efficiency is on-farm or district). Furthermore, completely different methodologies and assumptions are generally used, some of which appear to be inaccurate. This study was designed to review data presented in the previous court cases and determine the on-farm irrigation efficiency of CVWD. In order to prepare an accurate report, the following new information and data was generated as part of this study:

- o Acreage in Coachella Valley within the CVWD command area based on independent (DWR) analysis
- o Estimate of agricultural groundwater pumpage in CVWD

- o Current crop coefficients (Kc) and annual ET used by researchers for various crops
- o Long-term leaching requirement (LR)

2.4 STANDARD DEFINITIONS

These definitions are from current literature used for discussing irrigation efficiency. These reflect the current trends in describing the conditions of irrigation. These terms are specifically defined for evaluating on-farm irrigation efficiency.

Efficiency Terms

- o Beneficial Water Uses - At the farm level, this includes transpiration needed for desired crop growth (majority), leaching for salinity control (not including nonuniformity), special practices such as packing the soil for harvest, weed germination, climate control, and some percentage of tailwater, which helps maintain a favorable salt balance.
- o Nonbeneficial Uses - Weed transpiration, deep percolation in excess of leaching requirement, deep percolation due to nonuniformity of irrigation, evaporation from wet soil surfaces, evaporation from wet foliage, canal and pipe losses, and uncollected tailwater (minus some percentage which contributes to salt balance).
- o On-Farm Irrigation Efficiency - Defined as the ratio of the irrigation water beneficially used to the irrigation water applied to the fields. Beneficial water use is defined above.
- o Distribution Uniformity (DU) - Describes how evenly water is made available to crops in a field. DU is defined as the ratio of the depth of water received by the 25 percent of plants receiving the least amount of water, to the average depth of water received by all plants. Standard methods of determining DU are published in the Cal Poly (SLO) Irrigation Evaluation Manual (1992) and are used by the DWR Mobile Labs operating in Coachella Valley and throughout California. DU is typically low on coarse soils as compared to heavy soils regardless of irrigation system type.

Irrigation Terms

- o Microirrigation - The frequent application of water in small quantities directly on or below the soil surface. Microirrigation is typically synonymous with drip irrigation, but also includes microspray systems. Microirrigation is well suited to the CVWD where coarse soils and permanent crops are grown.

- o Row Irrigation - The application of water using furrows (3- to 6-foot centers) to irrigate. This method of irrigation can have high DUs if managed correctly on heavy soils.
- o Flat Irrigation - The application of water using borders (50- to 200-foot centers) in which almost the entire soil surface is covered with water during irrigation. This method of irrigation can have high DUs if managed correctly, on heavy soils and with adequate laser leveling.
- o Hand-Move Sprinklers - A portable sprinkler system that can be installed on a field consisting of aluminum mainlines and impact sprinklers on short risers. These are used for germination of salt-sensitive crops.
- o Tailwater (TW) - Represents the component of delivered water to a farm which runs off the lower end of the field. Tailwater is required to achieve a uniform surface irrigation of an entire field. More tailwater is needed for row irrigation than for flat irrigation.
- o Deep Percolation (DP) - Represents the component of delivered water that passes through the soil root zone.
- o Tile Lines - Buried perforated pipelines installed in a field to remove a shallow water table from the root zone of a crop. Lines are typically 4 inches in diameter and spaced between 50 feet to 200 feet, depending on the soil type of the field.

Crop Water Use Terms

- o Potential Evapotranspiration (ET_o) - This is the value of the maximum water use of an unstressed grass reference crop. ET_o is calculated on an hourly basis using weather data collected at each of the weather stations in DWR's CIMIS network. Hourly, daily, and annual ET_o values are published by DWR for the CVWD. In 1987, the ET_o of the Thermal CIMIS weather station was 73.1 inches.
- o K_c - The K_c is the crop coefficient. This value represents the multiplier for estimating the crop ET where $ET_c = (K_c) \times (ET_o)$. Values for K_c are constantly being updated and revised as new information is generated on different crops and varieties. The K_c is different at each growth stage of the crops.
- o Actual Crop Evapotranspiration (ET_c) - The actual crop evapotranspiration may not be as great as the crop evapotranspiration which is calculated using ET_o and K_c values if unintended stress occurs. In the CVWD, the coarser soils allow for unstressed crop ET_c requirements to be applied. Therefore, it was assumed the potential crop ET_c in the CVWD is equal to the actual crop consumptive use except for conditions (such as grapes) in which growers deliberately stress plants at certain times of the year for horticultural purposes.

- o Leaching Requirement (LR) - In arid or semi-arid conditions, rainfall is less than what a crop will use during a growing season. Since crops remove relatively pure water from the soil, salts from the irrigation water are left behind. Some plants, such as lettuce, are sensitive to salts. Other crops, such as cotton, are salt tolerant. LR is the fraction of the infiltrated irrigation water at a point in the field which deep percolates and is necessary to maintain a desirable salt balance at that point. The LR fraction does not include water needed to overcome deep percolation problems caused by nonuniformity (i.e., by a DU of less than 100 percent). Some amount of deep percolation at a point (in excess of the required LR) due to nonuniformity may be reasonable, but none of it is beneficial.
- o Leaching Fraction (LF) - The LF represents the actual fraction of water which deep percolates through the root zone and is considered to be beneficially used for salinity control. In this report, it does not include excess deep percolation caused by nonuniformity.
- o Effective Precipitation (EP) - The amount of rainfall in a year that can actually be used by the crops.

Acronyms and Names Used by Public Agencies:

- o CIMIS - California Irrigation Management Information System
- o CVWD - Coachella Valley Water District
- o CVRCD - Coachella Valley Resource Conservation District
- o DWR - California Department of Water Resources
- o EPA - Environmental Protection Agency
- o ESA - Endangered Species Act
- o Inlands Surface Waters Plan - New water quality objectives adopted in 1991 by the SWRCB placing numerical limits on specific constituents of surface waters including rivers, streams, and man-made agricultural drainage channels.
- o IID - Imperial Irrigation District
- o MWD - Metropolitan Water District of Southern California
- o NOAA - National Oceanic Atmospheric Association
- o SCS - Soil Conservation Service
- o SWRCB - State Water Resources Control Board

- o USBR - United States Bureau of Reclamation
- o USGS - United States Geological Survey

2.5 WHY 1987 WAS SELECTED

The calendar year 1987 was determined to be a fairly representative climate year for data analysis. Since a detailed analysis was required, only one year's data was evaluated. The most significant unknown value was the irrigated crop acreage in the CVWD command area. An in-depth agricultural land use study by the DWR was last done in 1987 for CVWD. The USGS report on groundwater conditions had published data through 1986. Complete 1987 power records for Coachella Valley agricultural pumping were available from IID (which has supplied power to the Coachella Valley since 1943). Aerial photography was also available from the same time frame. Selection of 1987 also allowed for optimal use of court data that was available.

Section 3

ON-FARM IRRIGATION EFFICIENCY

The basic idea of on-farm irrigation efficiency is fairly well understood. However, the methods used to calculate the variables in the equation vary widely. In its simplest form, the equation is as follows:

$$\text{On-Farm Irrigation Efficiency} = \frac{\text{Irrigation Water Beneficially Used} \times 100}{\text{Irrigation Water Applied}} \quad \text{Eq. (3-1)}$$

One of the major problems in educating the general public about agricultural water use is simply the wide variety of irrigation efficiency definitions. Equation 3-1, as stated above, is accepted by the California Department of Water Resources (DWR) Office of Water Conservation for use in the DWR water management programs. This equation is also accepted by definitions of the American Society of Civil Engineers (ASCE) Irrigation and Drainage Division.

Any comparison of on-farm irrigation efficiency (IE) calculations must carefully consider how "beneficial use" and "applied water" were both defined and computed. Discrepancies in estimates of IE arise because of several factors. Some of these differences are minor but others can significantly alter results on an analysis of a large area. It is the intention of this report to evaluate the current numbers and assumptions used by irrigation professionals and determine the most reasonable approach. The following are some of the factors that cause differences between reports:

- o Sources of water other than canal
- o Incorrect acreage
- o Actual crop ETs are less than potential crop ETs
- o Some of the ET is due to other sources of water
- o Potential crop ETs are not always known for a region
- o Actual leaching fraction (LF) can be less than the LR
- o Correct LR is debatable
- o Confusion between efficiency terms (distribution uniformity, on-farm irrigation efficiency, district irrigation efficiency, seasonal irrigation efficiency, single event irrigation efficiency, motor/pump efficiency, water use efficiency)
- o Errors when describing water use (reasonable vs. beneficial, actual vs. potential, theoretical vs. measured)

"Beneficially used irrigation water" has been defined earlier. The primary beneficial use components in 1987 for CVWD were (1) crop transpiration and (2) leaching for salt control. This report emphasizes the correct estimation of both parameters and utilized information from a variety of reputable sources.

Various publications have provided a range of values for ET_c of major crops in CVWD. Various references were analyzed for the accuracy and completeness of the data collection and estimation procedures. For some crops, this report compares reported ET_c values with calculations using transferrable techniques (e.g., K_c x ET_o) to determine the most reasonable and unbiased ET_c values. Of particular interest were the values for citrus in CVWD. Discrepancies between reported values of crop transpiration are discussed, and justifications are given for the values used in this report.

On the salt control aspect, a detailed discussion of LR computations is provided in the appendix of this report. Of particular note are (1) the correct definition of LR does not include deep percolation caused by nonuniformity, and (2) LR computations for nonpermanent crops must plan for the most salt-sensitive crop which will be grown in a crop rotation on a field rather than for the "average salt tolerance" of the rotated crops.

For the irrigation water applied, the reported on-farm water deliveries were used as the basis. CVWD measures and charges growers for the amount of water delivered to each field. The growers have the opportunity to scrutinize the billings for accuracy.

Taking into account the definition of beneficial use and the area where water is applied, the equation is restated as follows:

$$\text{Theoretical Irrigation Efficiency} = \frac{\text{Portion of Actual ET of Crops Supplied by Irrigation Water}}{(\text{Irrigation Water Dedicated to the Area}) * (1 - \text{LR})} \quad \text{Eq. (3-2)}$$

The geology of CVWD includes very sandy soil, which allows for considerable deep percolation of on-farm irrigation water. This deep percolation cannot be directly measured. Only part of this deep percolation water enters the Salton Sea through drain tiles; the majority of the remainder flows underground directly into the Salton Sea.

Therefore, CVWD must estimate the on-farm irrigation efficiency without ever having a means of verifying the accuracy of the computation. Specifically, the only way one can truly verify the accuracy of the IE computation is to be able to accurately measure all the deep percolation. Since this is impossible with the CVWD geology (and in most other areas of California as well), estimates of the on-farm irrigation efficiency are made with the following equation:

$$\text{On-Farm Irrigation Efficiency} = \frac{\text{Crop ET}_c - \text{Effective Rain}}{(\text{Delivered Water}) * (1 - \text{LF})} \quad \text{Eq. (3-3)}$$

This report shows that some of the numerical values which have been used in the historical CVWD computations are incorrect. Specifically, four errors have typically occurred with the computations:

- o The per-acre ETc of citrus in efficiency reports have generally been overestimated.
- o The cropped acreage which has been used in the computations has included all irrigated areas in CVWD rather than just the irrigated area served directly by the Coachella Canal (command area).
- o The "delivered water" must include all irrigation water delivered through on-farm irrigation systems (both from the Coachella Canals and from wells); well water has been underestimated.
- o The LF has included nonbeneficial components of deep percolation due to nonuniformity.

Section 4

ON-FARM IRRIGATION EFFICIENCY AND DISTRIBUTION UNIFORMITY

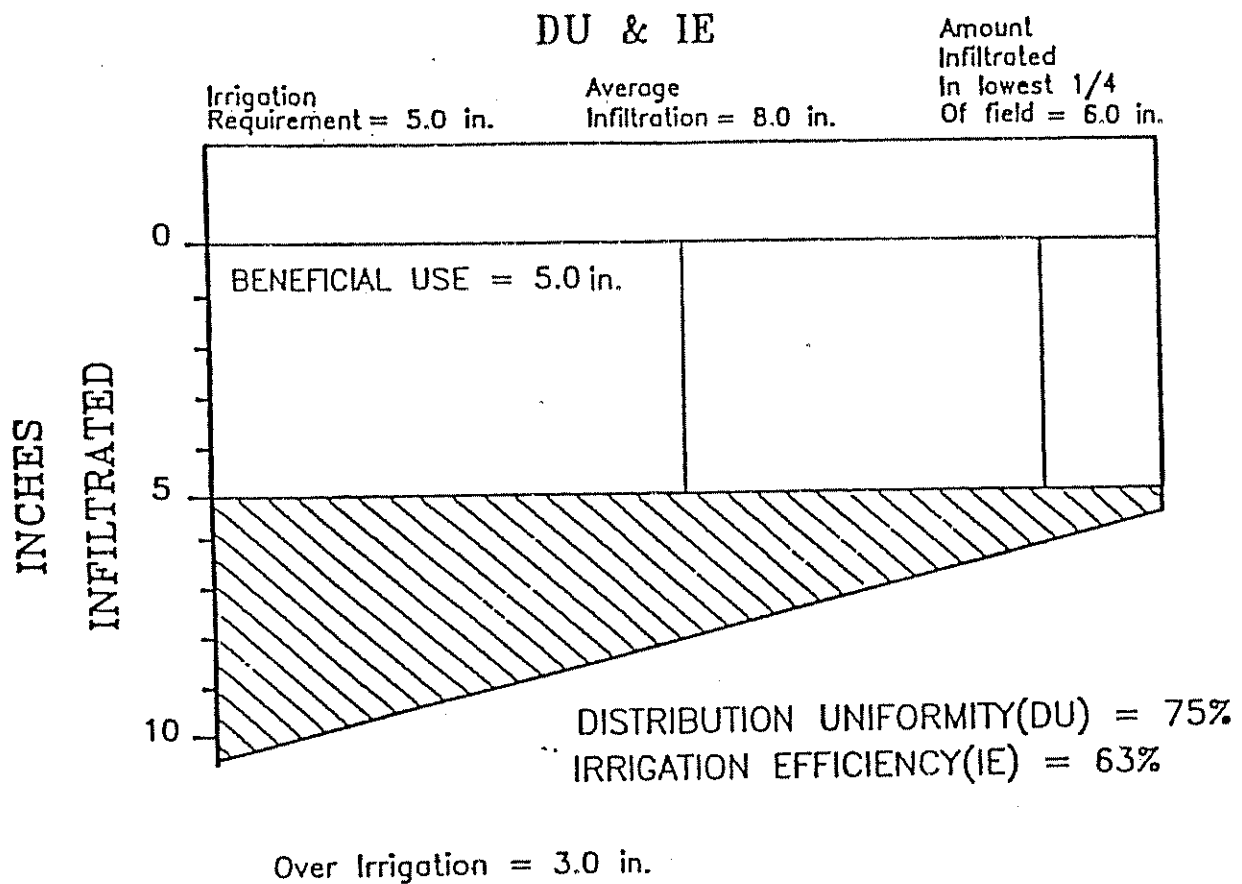
The Coachella Valley Resource Conservation District (CVRCD), assisted by the Soil Conservation Service, began performing irrigation system evaluations in the Coachella Valley in 1985. The main goal of the mobile lab is the measurement of distribution uniformity (DU) of the Coachella Valley's irrigation systems. The mobile lab does not typically perform measurements of the on-farm irrigation efficiency due to the complex and dynamic nature of determining the variables of a single event irrigation. The CVRCD has published some of the findings with respect to the operation of microirrigation systems in several reports. The most comprehensive report was released in 1991 titled "A Six Year Summary Analyzing Micro Irrigation Performance on Coachella Valley Farms." This section summarizes the findings of the CVRCD report and also includes discussions of other regions.

4.1 DISTRIBUTION UNIFORMITY

The distribution uniformity describes the evenness of water application. The field evaluation of distribution uniformity measures the ability of a system to deliver the same amount of water to each plant. When water is applied to a field, the water penetrates to different depths, depending on many factors. This can be shown two-dimensionally by plotting some finite amount of measured grid points from a field.

Rearranging the data from the largest to smallest amount of infiltrated water, the DU can be solved graphically as in Figure 4-1. The DU is the ratio of the depth of water infiltrated to the region receiving the lowest 25 percent of the infiltrated water to the average depth of the infiltrated water. Figure 4-1 was derived from CVWD Exhibit 1065 for the Torres-Martinez case for Coachella Valley. Assuming a grower wishes to optimize the application of irrigation water, the grower must take into account the DU when calculating the amount of water to apply. This means that if the calculated water requirement was 5 inches and the DU is 75 percent, the grower should apply a total of 6.7 inches ($5 \text{ inches} / 75 \text{ percent}$) to ensure that only the lower one-eighth of the field is underirrigated. If less than 6.7 inches of water is applied, then more of the field would be underirrigated. If more than 6.7 inches of water is applied, overirrigation would occur.

The only data that is published for the measure of DU in the Coachella Valley is for microirrigation systems. The results of 177 microirrigation irrigation evaluations performed between 1984 and 1990 resulted in an average DU of 76% (CVRCD, 1991). The range of measured values ranged from a low of 18% to a high of 97 percent. Only a portion (about 40%) of the Coachella Valley uses microirrigation. The majority of the Coachella Valley uses other irrigation systems that have considerable lower potentials for high DUs due to the sandy soils. With row irrigation in coarse sandy soils, it is difficult to achieve high DU values unless many structural and nonstructural improvements are made to the system. For example, a tailwater



Source: CVWD Exhibit 1065 Torres-Martinez Case

Assumptions: Sandy Soil
Zero Runoff
Beneficial Use (Irrigation Requirement) Includes Both
Crop Transpiration and Leaching for Salt Control

recovery system and shorter field lengths would be necessary to obtain high surface irrigation DUs in the Coachella Valley. Therefore, the average DU of irrigations of CVWD must be less than 76 percent. Furthermore, the inherent inefficiency of surface irrigation systems without tailwater recovery systems (as is the case in CVWD) on sandy soils means the IE must also be much lower than 76 percent.

4.2 RESULTS FROM OTHER REGIONS

Data reported by the Westlands Water District indicate high DUs are obtainable on row-irrigated fields with heavy soils. Westlands also found that by using Equation 3-3 (Section 3) the irrigation efficiency was overstated because of poor irrigation scheduling and nonuniformity (Westlands Water District, 1987). The average field distribution uniformity reported for 335 evaluations was 72 percent. This data included measurements on row-irrigated fields, drip irrigation, sprinkler irrigation, and combinations of systems.

Data from Monterey County Water Resources Agency indicate measured DUs of 68 percent for 72 irrigation evaluations performed by a mobile laboratory. Due to the high value of most crops grown in the Salinas Valley and based on field observations, all fields were assumed to be wetted sufficiently. The distribution uniformity for Salinas Valley is therefore the upper limit of the on-farm irrigation efficiency.

4.3 IRRIGATION EFFICIENCY

To state that the irrigation efficiency is greater than the DU would require that a large portion of the fields be underirrigated. Based on visual observations of CVWD and discussions with local irrigation specialists, this does not appear to have occurred in 1987. In other words, the on-farm irrigation efficiency must be less than the measured DU for the district. In the example shown from CVWD data on Figure 4-1, the on-farm irrigation efficiency for this field event was 63 percent.

Westlands Water District reported on-farm irrigation efficiency of 64 percent (Westlands Water District, 1987). For Salinas Valley, the on-farm irrigation efficiency is less than 68 percent (based on the available data).

In summary, the distribution uniformity of the CVWD command area is less than 76 percent. Due to the conditions in the Coachella Valley, the irrigation efficiency must be less than the DU.

Section 5

WATER AVAILABILITY IN STUDY AREA

5.1 SURFACE WATER DELIVERY

Data reported in the Torres-Martinez court case was used to evaluate the total volume of water delivered by the USBR to CVWD. The CVWD command area received 325,000 acre-feet in 1987 below Check 6A as the reference point. Water accounted for and charged to the agricultural water users was 279,000 acre-feet. The difference of 46,000 acre-feet (14%) is accounted for from operational discharges, seepage from pipelines, and seepage/evaporation from canals and storage reservoir.

5.2 IRRIGATED ACREAGE

Reported irrigated acreage varies considerably depending on the source of the information. This is due to several factors:

- o Time of year for determination.
- o Groupings of the crops. (Specific guidelines are different for DWR or the county agricultural commissioner's offices.)
- o Harvested vs. planted acreages. (Some crops are planted in the fall and harvested in the next spring.)
- o Database source (internal vs. external records).

CVWD reported acreage was not used because the data included lands outside the command area.

Included in Appendix B is a detailed breakdown of the data collected from the December 1990 report by DWR entitled "South Lahontan and Northern Colorado Desert Land Use Study, 1987" by crop and USGS quadrangle reference. Additional information used in the generation of the DWR report was obtained from the DWR Southern District office in Glendale, California. Additional data included the computer "tab" data files as well as the published report material. DWR drafted results of its aerial and ground truthing analysis onto United States Geological Survey (USGS) 7-1/2 minute quadrangle sheets for the 1987 crop year. Each quadrangle with cropped acreage was copied and compared to the service area boundary of the CVWD as reported on CVWD Drawing No. 48A dated March 1986. Each quadrangle was then summarized by crop for the irrigated acreage within the command area and outside the command area.

Aerial photography used in the DWR analysis was obtained from the USGS. The aerial photographs were from 1985. Adjustments were made to the data by DWR to reflect the growing conditions in 1987. Acreage within the CVWD service area or "command area" was calculated separately from the acreage outside of the service area boundaries for this report. Separation of the acreage was not done in the summary information published by the DWR report or by CVWD. Table 5-1 is a summary of the investigation into the irrigated acreages both within and outside of the CVWD command area. The summary includes a calculation of the double-cropped acreage.

5.3 GROUNDWATER PUMPING

5.3.1 Groundwater Usage in CVWD

Groundwater pumping in the CVWD supported irrigated agriculture until 1949 and is used today to provide irrigation water to areas both inside and outside of the CVWD command area. Additionally, the groundwater use is increasing due to urban demands since all urban water in Coachella Valley is supplied by groundwater.

Figure 5-1 shows approximate soil profiles of both the Imperial and Coachella Valleys. This figure illustrates the major difference between the two valleys. In Imperial Valley, there is a clay layer on the surface that corresponds to heavy soil type that has low permeability and is difficult to infiltrate water and also drain. In the Coachella Valley, surface soils are typically light soils impacted by the presence of the shallow water table.

CVWD previously reported 34,400 AF of agricultural groundwater pumping in 1987 (Bookman-Edmonston, 1989). However, the flows on agricultural pumps are not metered; therefore, there have been no direct measurements. Instead, there have been various modeling studies on the groundwater basin as a whole using various assumptions. No study was found that had good data for agricultural pumping volumes for the command area.

5.3.2 Notes from Coachella Valley Groundwater Reports

DWR Bulletin No. 108 groundwater investigation was done in response to rapid expansion of both irrigated agricultural and urban lands within the Coachella Valley. The investigation was requested by CVWD in 1960. In general, the study was designed to analyze the groundwater in Coachella Valley for planning purposes. Shallow groundwater conditions were adversely impacted with the introduction of the Colorado River water supplies in 1949 especially in the region south of Indio.

The DWR study delineated four subbasins and four areas of the Coachella Valley Groundwater Basin. Of primary concern to the agricultural areas of the lower Coachella Valley is the Indio Subbasin. The Indio Subbasin is divided into five subareas. The Palm Springs subarea is the forebay or main area of recharge to the Indio Subbasin. The Thermal subarea is the pressure area within the subbasin. The Palm Springs subarea is where water is applied for the DWR/MWD/CVWD groundwater management program. The Thermal subarea is primarily where agriculture is located in the lower Coachella Valley. Within the Thermal subarea, there is

TABLE 5-1
CVWD - 1987 CROP ACREAGE SUMMARY

Crop (1)	Coachella Valley Irrigated Ag. Acres (2)	Gross Irrig. Ag. Acreage Outside of CVWD Supply (3)	Gross CVWD Command Acreage Irrigated (4)	Net (95%) Acreage Outside of CVWD Supply (5)	Net (95%) CVWD Command Acreage Irrigated (6)	Net (95%) Acreage Outside of CVWD Supply w/Double Crop (7)	Net (95%) CVWD Command Acreage Irrigated w/Double Crop (8)
Alfalfa	2,616	0	2,616	0	2,485	0	2,485
Broccoli	1,427	0	1,427	0	1,356	0	2,711
Carrots	1,509	82	1,427	78	1,356	156	2,711
Dates	5,925	609	5,316	579	5,050	579	5,050
Grapefruit	8,013	1,959	6,054	1,861	5,751	1,861	5,751
Grapes	20,077	6,514	13,563	6,188	12,885	6,188	12,885
Lemons	2,555	1,085	1,470	1,031	1,397	1,031	1,397
Lettuce	2,171	231	1,940	219	1,843	439	3,686
Mixed Pasture	1,570	149	1,411	151	1,340 ✓	151	1,340
Oranges	3,412	413	2,999	392	2,849 ✓	392	2,849
Misc. Truck	4,355	516	3,839	490	3,647	980	7,294
Misc. Field	1,488	535	953	508	905	1,017	1,811
Misc. Perm.	1,868	378	1,490	359	1,416 ✓	359	1,416
Ag. Ponds	1,040	1,040	0	988	0	988	0
Total	58,026	13,521	44,505	12,845	42,280	14,141	51,386

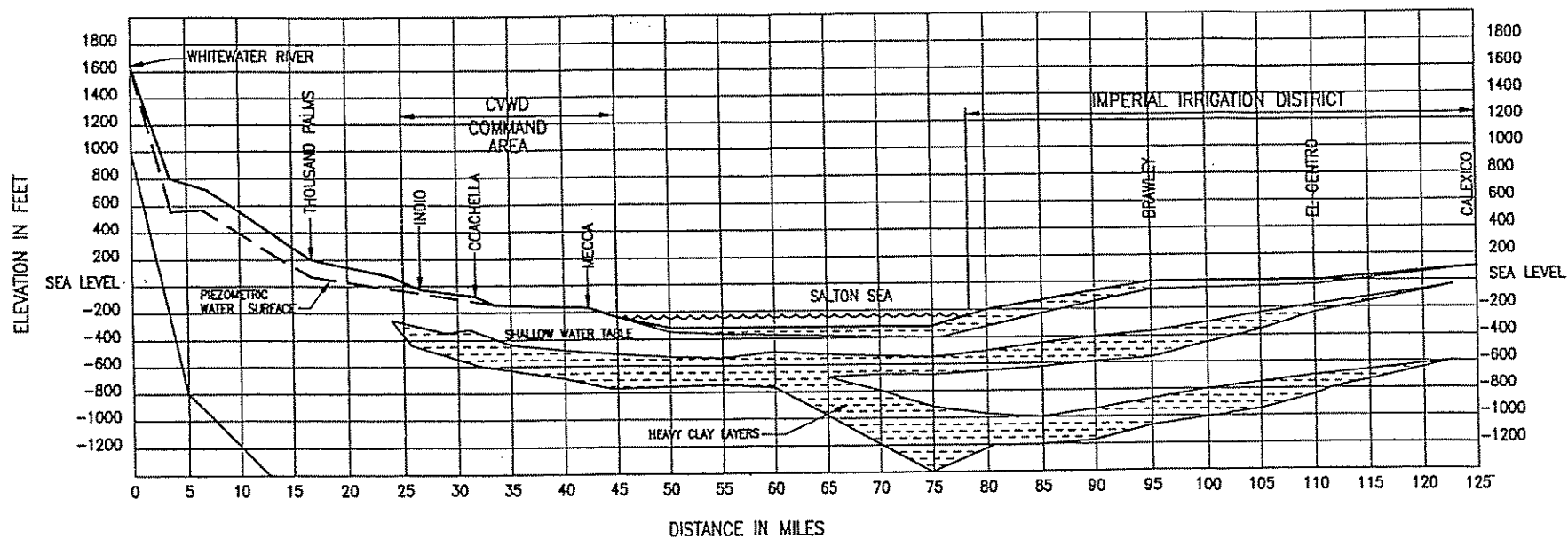
See next page for column descriptions.

TABLE 5-1 (continued)

Column Descriptions

1. Crop description.
2. Source: South Lahonton and Northern Colorado Desert Land Use Survey, DWR, 1990.
3. Determined by plotting CVWD boundary of command area on USGS quad sheets provided by DWR, 1990 report (Appendix C).
4. Determined same as Column 3.
5. Column 3 times 0.95 to account for a 5% acreage reduction due to farm roads and farmsteads.
6. Column 4 times 0.95.
7. Column 5 plus crops that were double cropped (carrots, lettuce, miscellaneous truck, and miscellaneous field).
8. Column 6 plus crops that were double cropped (broccoli, carrots, lettuce, miscellaneous truck, and miscellaneous field).

Refer to Appendix C for a detailed breakdown of the cropped acreage.



SOURCE:
CVWD EXHIBIT 1041, TORRES-MARTINEZ CASE AND PRELIMINARY
FINDINGS OF IMPERIAL COUNTY GROUNDWATER INVESTIGATIONS

IMPERIAL IRRIGATION DISTRICT/COACHELLA VALLEY WATER DISTRICT GROUNDWATER BASIN PROFILE

a lower aquifer below the aquitard shown on Figure 5-1 where the agricultural pumping for the CVWD command area is done. Above the aquitard is a semiperched groundwater zone of unusable water. The semiperched groundwater is removed by on-farm tile systems, leakage to the lower zone on the fringes of the CVWD command area, and an unknown component of subsurface flow to the Salton Sea. There is not adequate data available to determine the amount of subsurface flow to the Salton Sea.

The 1964 DWR study indicated that annual agricultural groundwater extractions were approximated at 115,000 acre-feet. Since that time, additional agricultural acreage has been added, especially outside the CVWD command area. This new acreage was served entirely by groundwater supplies. Also, beginning in the 1970s, growers began using microirrigation systems on permanent crops. To increase the flexibility of using these systems, growers installed wells to supply these new systems.

The pumped groundwater comes from the following sources:

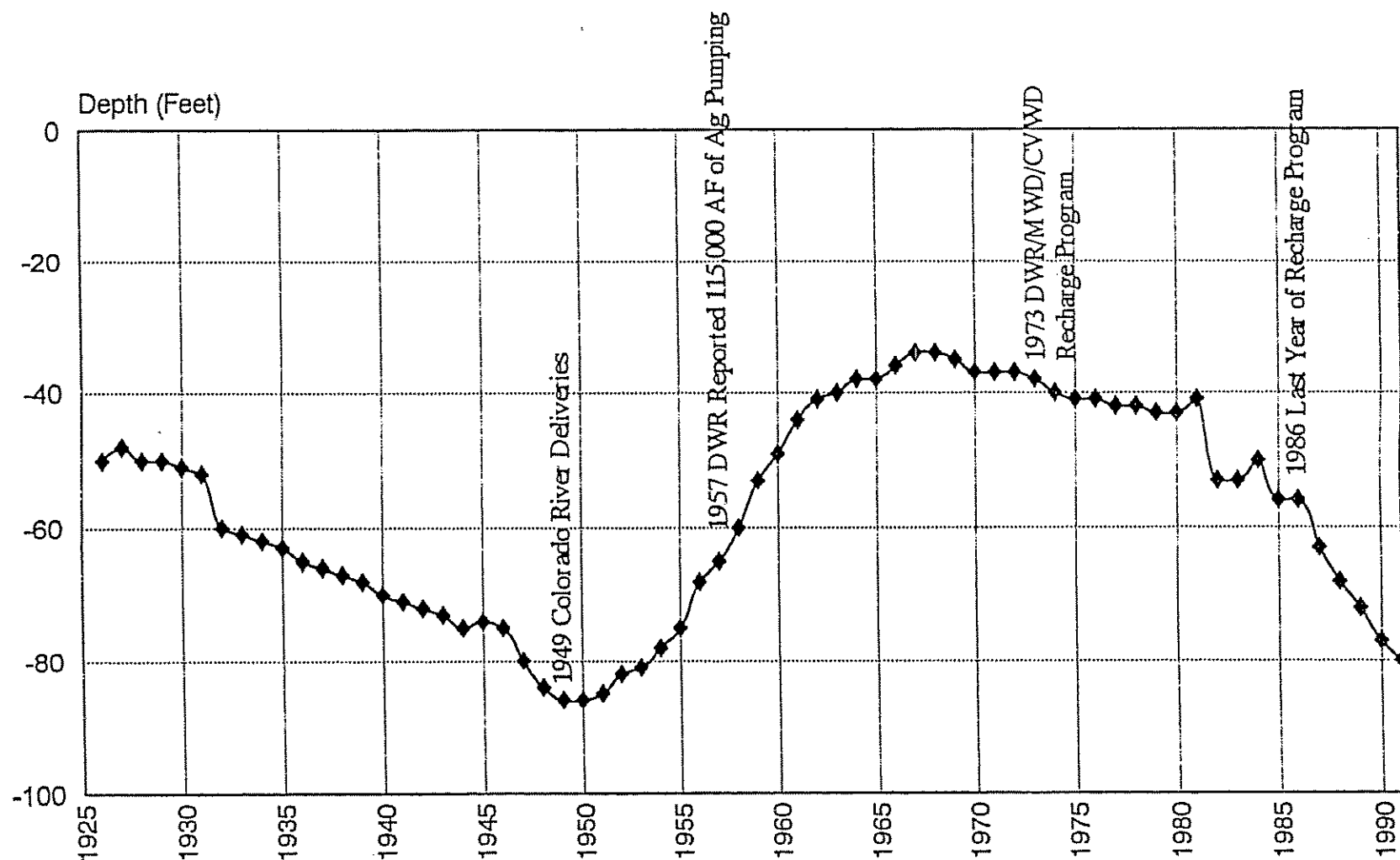
- o Upper basin recharge from the Palm Springs subarea.
- o Natural inflow from precipitation.
- o Infiltration from canal seepage and irrigation. This occurs from leakage through the aquitard and along the fringes of the clay layers.
- o Removal of groundwater storage.

USGS Report 91-4142 indicated that flows from the upper Coachella Valley recharge area to the lower Coachella Valley pressure area was occurring. Without additional modeling of the lower Coachella Valley, the USGS study concluded that it was not possible to assess the quantity of subsurface flows. Previous models and analysis have assumed a constant head boundary between the upper and lower Coachella Valley and the USGS study concluded that this assumption was not valid. In other words, the lower Coachella Valley is affected by the recharge efforts in the upper Coachella Valley.

Exhibit 1044 of the Torres-Martinez case included historic groundwater elevations from wells on the east and west sides of the lower Coachella Valley and are included in Appendix D. In general, the data reflect the trends shown on Figure 5-2. This data was from Exhibit 1044 of the Torres-Martinez case. Figure 5-2 shows that groundwater elevations were dropping until 1949, when deliveries from the Colorado River were initiated. Groundwater levels rose in response to leakage of groundwater from the semiperched zone of the Thermal subarea. Groundwater levels were rising in 1957 when 115,000 acre-feet of agricultural water was extracted (DWR Bulletin 108). Groundwater levels rose and were maintained into the 1980s. After the DWR/MWD/CVWD recharge program was discontinued in 1986, groundwater elevations have begun to drop off rapidly, indicating significant groundwater pumping.

These previous reports did not perform a thorough analysis of the agricultural groundwater pumping in the CVWD command area. In order to obtain a more precise value for the volume of groundwater pumped by growers within the CVWD command area, actual power usage for agricultural pumping (PA rate) was utilized in this report.

Groundwater Elevations Near Valerie Average Annual Depth from Ground Surface



Reference: Coachella Valley Water District - Well 07S08E34G01S